

## COFFEE WATER FOOTPRINT FOR WATER MANAGEMENT IN DAK NONG, THE CENTRAL HIGHLAND OF VIETNAM

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### ABSTRACT

*The Dak Nong province is in the Central Highland. The natural condition of its land, soil and climate that well supports to coffee cultivation. To grow one coffee crop, it requires much water for irrigating. In rain season, irrigated water is from rain water. And, in the dry season the irrigated water is from surface and ground water. The current changes of climate caused the long dry season with high temperature and low rainfall in rain season. These have strong impacted on coffee cultivation and production. This paper applied the methods of remote sensing and GIS in the water footprint analysis by CROPWAT model to identify the crop evapotranspiration, water footprint, blue water footprint, and green water footprint of coffee farming in Dak Nong province. Then, the conclusions and suggestions for water resource management and protection for proper water using and sustainable development of this province.*

**KEYWORDS:** *Coffee Water Footprint, Coffee Blue Water Footprint, Coffee, Green Water Footprint, Coffee Crop Evapotranspiration & Water Resources*

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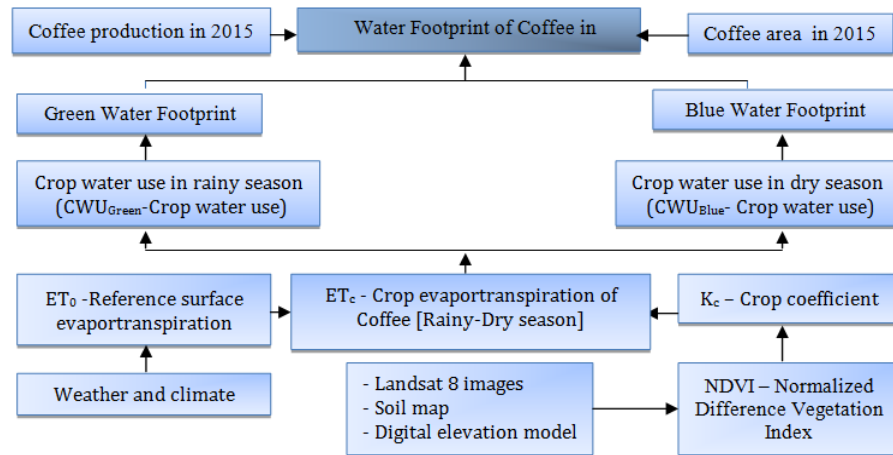
### INTRODUCTION

Coffee is one of the most traded agriculture products in the world. It is planted and produced in more than sixty countries. In which, Brazil and Vietnam are the world largest exporters of robusta coffee (Ipsos, 2013). The coffee industry in Vietnam has big contribution to national exportation. And, because the high demand of world coffee increases, coffee area is expanding in Vietnam, especially in the Central Highland, where Daknong has rapidly increased the coffee area in recent years. To 2016, coffee area in Daknong was 118,832 hectares. However, the Vietnam Ministry of Agriculture and Rural Development (MARD) planned to 2020 coffee area in Daknong would be only 69,000 hectares; (MARD, 2012; Daknong People Committee, 2016). This requires more water for coffee irrigation in this province. The recent reports of water degradation by deforestation, climate changes with more droughts, longer dry season, and much water exploitation has seriously threatened water sources in this area (Phan, 2012; DARD, 2013&2015).

This paper aims to identify the water footprint of harvested robusta coffee, green water and blue water for the coffee area in this province, by using FAO-CROPWAT model (Allen *et al.*, 1998; Smith, 1992; and Hoekstra *et al.*, 2007 & 2009). This model helps to calculate the right water usage needed for growing coffee trees to support for water resource management of this area. Water footprint analysis is a process to evaluate the water accessibilities in many dimensions for different purposes of human being (Hoekstra *et al.*, 2011). Water footprint not only measures the direct or indirect consumption of fresh water to produce the product, it also to identify the water catchment, water areas and times of water using (UNEP, 2010). In which, the water footprint measures of coffee

includes the water usage and water evaporation to produce one ton of coffee bean for both blue water footprint and green water footprint (Hoekstra and Chapagain, 2007; and Hoekstra *et al.*, 2013).

With CROPWAT model, this paper applied the remote sensing and GIS methods to calculate the water footprint for coffee cultivation in Daknong, and to answer the questions of how is the water need for one hectare of coffee per year? What kind of water sources are exploited for coffee? Are these exploitations properly? Then the solutions will be developed to properly use the water sources for coffee cultivation.



**Figure 1: Study Framework for Water Footprint of Coffee Cultivation in Daknong Province**

Source: by authors

## RESEARCH METHOD AND DATA DESCRIPTION

The water footprint approach for coffee in this study is to identify the direct water usage (the amount of water for coffee crop) and indirect water usage (the amount water for coffee, dry processing) to produce one ton of coffee bean examined in coffee dry process in Dak Nong province. The data inputs and methods used in this research are described below.

### Data Description

**Landsat Images:** Acquisition date: 16/10/2015; ID: LC81240512015289LGN00 (Coordinate: 13.01238, 108.19205; Path: 124, Row: 51); ID: LC81240522015289LGN00 (Coordinates: 11.56777, 107.8751; Path: 124, Row: 51); source:

<http://earthexplorer.usgs.gov/>;

**DEM Data:** The DEM images with tiff format and 30x30m pixel; ID: 20160810093535\_1284266679.tif. This data was to calculate the crop reference evapotranspiration ( $ET_0$ ) and covered the whole study area; source: <http://gdex.cr.usgs.gov/gdex/>;

The maps collection included a soil map and map of the coffee area in 2015;

The climate data collected in thirteen hydrometeorology stations of Dak Nong province in 2015. They included the monthly data of maximum and the minimum average temperature, average humidity, average wind speed, hours of sunshine, and average rainfall. These average monthly data were used to have the annual average data and to calculate the

crop reference evapotranspiration; and

Softwares of ENVI and Arc GIS

## METHODS

### The Remote Sensing Method

The Landsat images were used to identify the coffee area, vegetation index (NDVI) and crop coefficient ( $K_c$ ) of coffee in Dak Nong in 2015. The NDVI index was calculated by the ratio of Red and NIR spectral bands (Benedetti and Rossinni, 1993). It then helped to calculate the crop coefficient ( $K_c$ ) and crop reference evapotranspiration ( $ET_o$ ) of coffee. According to Singh and Irmak (2009), to calculate  $K_c$ , it required the data of coffee density, stages of coffee growth and natural conditions of the area. The relationship of these elements to the vegetation index (NDVI) is described and the following Table 1:

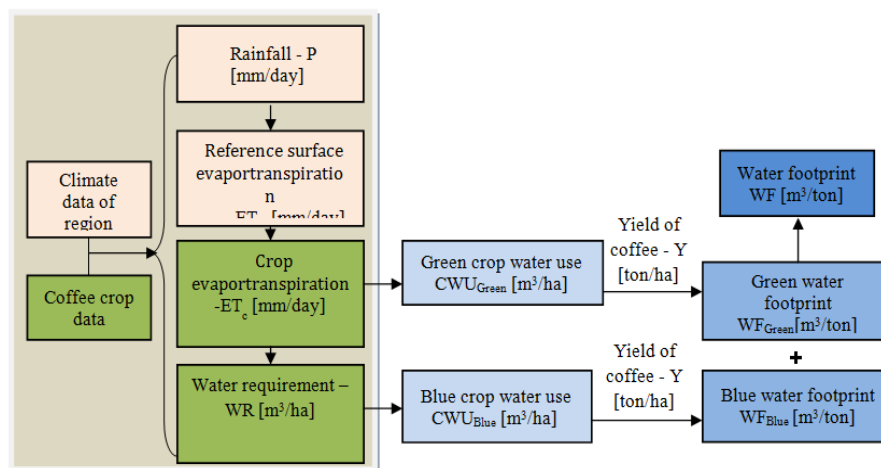
**Table 1: Relationship of NDVI and  $K_c$**

Index	$K_c$	NDVI
Related elements	Stages of growth Coffee seeds Natural conditions	Coffee density The growth statuses of coffee The space and time to grow coffee

### The GIS Method

The results of NDVI and KC from remote sensing analyses were put into GIS and integrated with soil and climate data, using CROPWAT model, to calculate the crop reference evapotranspiration ( $ET_o$ ) (Smith, 1992; Allen *et al.*, 1998; Singh and Irmak, 2009; and Luis *et al.*, 2014). These results helped to identify the crop blue reference evapotranspiration ( $ET_{Blue}$ ) and the crop green reference evapotranspiration ( $ET_{Green}$ ) for coffee in this area.

From then, the crop water use was calculated to include the fresh water use in the dry season ( $CWU_{Blue}$ ) and the fresh water use in rain season ( $CWU_{Green}$ ) (Hoekstra *et al.*, 2009&2011). These indexes were used to identify the blue water footprint and the green water footprint for one ton of coffee bean in this province (by the coffee dry process). The water footprint map for coffee, established on Model Builder of ArcGIS, was presented in the Figure 2 below:



**Figure 2: The Process of Calculating the Water Footprint of Coffee by GIS Technique**

Source: Development from the approach of Hoekstra *et al.*, 2009

## DISCUSSIONS AND RESULTS

### The Crop Evapotranspiration in Coffee area of Dak Nong Province

The examined areas are mature robusta coffee farms (over four years old) in Daknong province. The crop duration lasts in eleven months. Table 2 shows the different results of NDVI and K<sub>c</sub> indexes. The areas with NDVI > 0.7 and K<sub>c</sub> > 0.8 had coffee farms in high coffee tree density (from 1,300 to 1,500 tree per hectare), high coffee branches density (average from 100 to 120 branches per tree) (the districts of Dak Mil and Tuy Duc). The areas with NDVI < 0.7 and K<sub>c</sub> < 0.8 had coffee farms in average coffee tree density (from 1,000 to 1,100 trees per hectare) and average coffee branches (from 80 to 100 branches per tree) (the districts of Cu Jut, Gia Nghia and Dak Glong). Other three districts (Krong No, Dak Song and Dak R'Lap) with NDVI < 0.7 and K<sub>c</sub> > 0.8 had farms in low coffee tree density (from 1,000 to 1,100 trees per hectare) and average branches density (from 80 to 100 branches per tree). This was because farmers in different areas applied different seeds and methods for their coffee farming.

Within Dak Nong, the climate and natural condition are various in different areas. Some districts have high crop evapotranspiration index, etc. =  $1,243 \div 1,284$  mm (in the districts of Cu Jut and Krong No), because these areas have the annual average temperature from 24 - 26<sup>0</sup>C, the annual average total temperature above 9,000<sup>0</sup>C, the annual average wind speed of 3,2 - 5,4 m/s, and the average elevation from 700 to 900 meters. Other districts (Dak Song, Tuy Duc, Gia Nghia, Dak Glong and Dak R'Lap) had the Etc ≤ 1,200 mm, because they have the annual average temperature from 23 - 25<sup>0</sup> C, the annual average total temperature below 8,000<sup>0</sup>C, the annual average wind speed from 2,5 - 3,0 m/s, and the average elevation from 600 to 800 meters. The Table 2 indicated that the evapotranspiration increased the more difficulties of climate, geography, and cultivation experiences of farmers (such as coffee seeds, coffee density, and irrigation, etc.). These results had the same conclusion as Champagne and Hoekstra (2007).

**Table 2: Statistics of NDVI and K<sub>c</sub> Indexes of the Coffee Crop**

Average Value	Districts							
	Cu Jut	Dak Mil	Krong No	Dak Song	Dak Glong	Gia Nghia	Tuy Duc	Dak R'Lap
NDVI	0.680	0.703	0.683	0.689	0.652	0.625	0.717	0.684
K <sub>c</sub>	0.762	0.861	0.824	0.819	0.762	0.787	0.814	0.830
ET <sub>c</sub> (mm/period)	1,284.52	1,207.73	1,243.80	1,133.83	1,088.24	1,128.47	1,162.77	1,195.24
ET <sub>Blue</sub> (mm/period)	442,666	327,683	373,769	279,242	277,665	252,044	282,042	278,139
ET <sub>Green</sub> (mm/period)	841,849	880,043	870,03	854,583	810,577	876,429	880,728	917,098

**Source:** Result analyzed from remote sensing method

### The Water Footprint of Coffee Crop in Dak Nong Province

#### The Requirement Water of Coffee Tree in Dak Nong Province

The Table 3 and in Figure 3 shows that the consequence of water footprint analysis indicated the biggest differentiation of the requirement of water for coffee trees in rain season (CWU<sub>Green</sub>) and dry season (CWU<sub>Blue</sub>) of the districts. The CWU<sub>Blue</sub> was ranked from 2,520 – 4,426 m<sup>3</sup>/ha. It was higher in the districts of Cu Jut, Krong No and Dak Mil (from 3,276 to 4,426 m<sup>3</sup>/ha); Cu Jut was the highest. Other districts had the lower requirement of water, from 2,520 to 2,792 (m<sup>3</sup>/ha). This difference came from the different impacts of climate (temperature, humidity, and the hours of sunshine), typology and coffee seeds. The amount of water one coffee tree really needs in the dry season is about 450 to 500 liter/tree for one irrigation time, while in practice farmers irrigated much more than the tree need (from 800 to 1,000

liter/tree/irrigation time). This has caused the biggest waste of fresh water in coffee cultivation in this province. Amongst districts, Gia Nghia had the lowest consumed water of coffee trees in dry season. It was because farmers in this area applied the coffee seed that required less water.

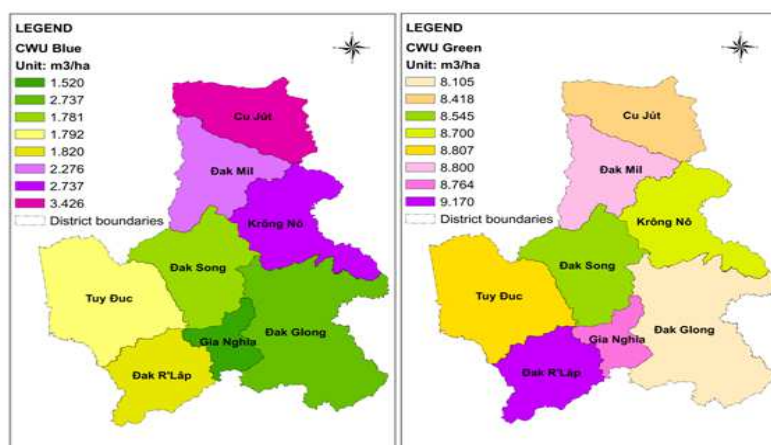
In general, the annual rainfall from 2,200 to 2,400 mm of Dak Nong province can redundantly supply water for coffee in rain season. However, the water requirement for coffee in districts is different because of different coffee areas. The districts of Dak Mil, Krong No, Dak Song, Tuy Duc, and Dak R'Lap had large coffee area (over 14,000 hectares of each). These areas have a good natural condition for high coffee production. Therefore the fresh water requirement in these districts was higher than others, from 8,500 to 9,100 m<sup>3</sup>/ha. Gia Nghia and Dak Glong had coffee areas around 7,000 hectares of each (about 48 percent of total district agriculture area). Their water requirement in the rain season was from 8,100 to 8,700 m<sup>3</sup>/ha. This amount of water was close to the above districts with over 14,000 hectares of coffee due to high density (from 1,100 to 1,200 trees/hectare)

Especially in Cu Jut district, the coffee area was 2,977 hectares, quite lower than others. The water requirement in the rain season was 8,400 m<sup>3</sup>/ha, nearly the same with Gia Nghia and Dak Glong with 7,000 hectares. The coffee density in this area was lower as well, because of limited natural condition (with low humidity, heat and dry) and high slope (over 5 sloped degrees); and farmers applied the coffee seeds required much water. They had no vegetation cover for their farms. Therefore, their coffee yield was lower than others.

**Table 3: Average Water Footprint of Coffee crop for Harvesting in Dak Nong Province**

Districts	Areas (ha)	Yield (ton/ha)	CWU <sub>Blue</sub> (m <sup>3</sup> /ha)	CWU <sub>Green</sub> (m <sup>3</sup> /ha)	WF <sub>blue</sub> (m <sup>3</sup> /ton)	WF <sub>green</sub> (m <sup>3</sup> /ton)	Total WF (m <sup>3</sup> /ton)
Cu Jut	2,977	2.19	4,426.66	8,418.49	2,021.31	3,844.06	5,865.37
Dak Mil	21,009	2.44	3,276.83	8,800.43	1,342.96	3,606.73	4,949.70
Krong No	14,495	2.41	3,737.69	8,700.30	1,550.91	3,610.08	5,160.99
Dak Song	23,552	2.29	2,792.42	8,545.83	1,219.40	3,731.80	4,951.20
Dak Glong	7,403	2.19	2,776.65	8,105.77	1,267.88	3,701.26	4,969.14
Gia Nghia	7,180	2.24	2,520.44	8,764.29	1,125.20	3,912.63	5,037.83
Tuy Duc	14,590	2.13	2,820.42	8,807.28	1,324.14	4,134.87	5,459.01
Dak R'Lap	16,552	2.19	2,781.39	9,170.98	1,270.04	4,187.66	5,457.70
Average		2.26	3,141.56	8,664.17	1,390.23	3,841.14	5,231.37

Source: Result analyzed from GIS method by authors



**Figure 3: Maps of the Crop Water Use of Coffee in Dak Nong Province**

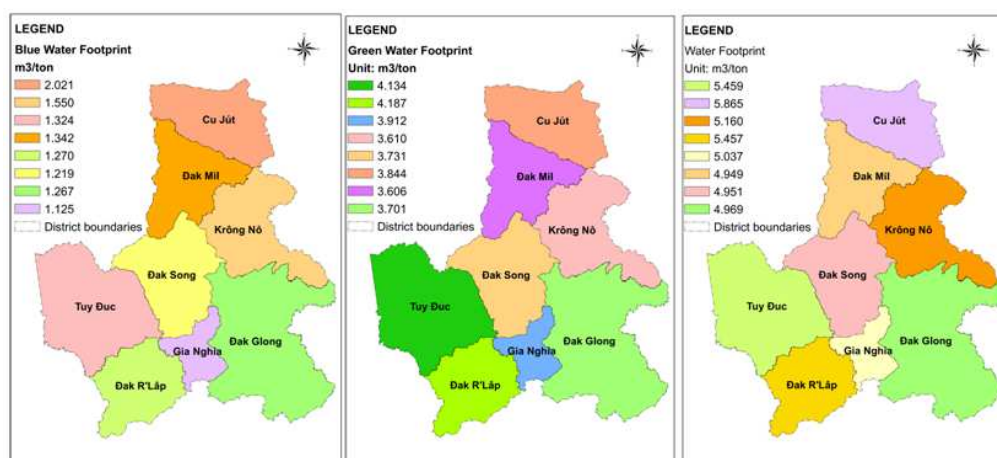
Source: The results of calculating the crop water use of coffee by GIS technique, developed by the authors

### Water Footprint of Coffee in Dak Nong

The results in Table 3 and in Figure 4 describes the average consumed water for producing one ton of coffee bean, by coffee, dry process, was 5,231 m<sup>3</sup> of water/ton. In which, the blue water footprint (WF<sub>blue</sub>) was 1,390 m<sup>3</sup>/ton and the green water footprint (WF<sub>green</sub>) was 3,941 m<sup>3</sup>/ton. These were the same with Chapagain and Hoekstra's results when they calculated the water footprint for Vietnamese coffee in 2007 was 5,086 m<sup>3</sup>/ton in yield (Chapagain and Hoekstra, 2007).

By the above results, the total water footprint (WF) in the districts was also different, because of different blue water footprint and the green water footprint of districts. Cu Jut had the highest WF (5,865 m<sup>3</sup>/ton) because it has the driest and warmest climate. The others had WF from 4,949 to 5,459 m<sup>3</sup>/ton; because of easier climate. Except Tuy Duc, the WF was about 5.459 m<sup>3</sup>/ton, but the coffee yield was low (2.13 ton/ha); because coffee trees here were very old and had a slow growth process. In contrast, the WF of Gia Nghia and Dak Glong was about 5,000 m<sup>3</sup>/ton, lower than Cu Jut; because the new coffee seed needs less water and these areas have better natural condition for coffee.

Table 3 also shows the different crop water use (CWU<sub>blue</sub>) led the different water footprint in districts. And, the independent elements that caused the changes of the water footprint of districts were climate and hydrometeorology, typology and soil in the areas, coffee seeds, and water irrigation of farmers.



**Figure 4: Maps of Water Footprint of Coffee in Dak Nong Province**

**Source:** The results of calculating the water footprint of coffee by GIS technique, developed by the authors

### CONCLUSIONS

With the above results, the paper could conclude on the blue water footprint (WF<sub>blue</sub>), green water footprint (WF<sub>green</sub>), and total water footprint (WF) for districts in Dak Nong province. The WF<sub>blue</sub> refers to the climate, natural condition, and surface water of the districts. In contrast, the WF<sub>green</sub> refers to the coffee seeds and water irrigation. The districts that had difficult climate and less surface water; the WF<sub>blue</sub> would increase. And, if farmers apply good seeds with less water requirement, the WF<sub>green</sub> would decrease. Therefore, the districts that had high WF need to adjust the proper input elements of coffee farming (such as coffee seed, coffee density, water irrigation as well as an irrigation system). The water use of coffee was different in districts. The coffee farms in difficult climatic areas require much more water in dry season (such as the districts of Tuy Duc, Krông Nô, and Cu Jut). This will bring the fresh water shortage for these areas in the future.

The average coffee, water footprint in Dak Nong province was 5,231.37m<sup>3</sup>/ton/crop. In which, the green water footprint was 73.4 percent and the blue water footprint was 26.6 percent. This conclude the role of green water footprint in maintaining the coffee yield; and the role of blue water footprint in blooming and having fruits. In sum, coffee farming has strong dependence on water source and natural conditions. In adjusting the coffee water footprint, it could maintain the water sources for coffee cultivation.

## SUGGESTIONS

To the point of view for water conservation and proper usage for sustainable development, coffee farming in Dak Nong province has increased impacts on water resource, especially surface and ground water resources. It is necessary to have better strategies for water using and solving problems of increasing water requirements, while fresh water sources is being decreased in this province. Firstly, it is necessary to identify the characteristics of river catchment and the areas where would be available for cultivation. This should be considered with a balance between water demand and water supply for agriculture activities that would not damage the water resource and ecology of the Highland area.

To reduce the coffee green and blue water footprints, the crop evapotranspiration should be reduced and controlled. At the government level, the irrigation system should be well developed to collect storm water for using in the dry season; the land use planning for agriculture area should be implemented. Then the areas with less support for coffee farming should be prohibited; the new seeds with less consumed water should be encouraged to develop. And to farmers, their awareness of water conservation and protection should be increased; and the guideline for coffee farming should be updated to support well for their farming.

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